Journal of Cultural Heritage 31S (2018) S3–S9

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Original article

State-of-the-art on methods for reducing rising damp in masonry

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ARTICLE INFO

Article history:
Received 29 January 2018
Accepted 4 April 2018
Available online 21 April 2018

Keywords:
Rising damp
Masonry walls
Capillary absorption

ABSTRACT

Several materials and technologies have been proposed over last century to fight the capillary rise of water from ground in historic masonry buildings. These methods involve different operational principles and different strategies to cope with rising damp, which is one of the most critical problems in the conservation of architectural heritage. However, despite the extensive use of these technologies in historic buildings, the data about their actual effectiveness in the field are still quite limited and the reasons for their success or failure in real masonries have not been fully elucidated yet. This paper provides an overview of the technologies for the removal of rising damp and a state-of-the-art on the results so far obtained by research, both in laboratory and on-site.

1. Introduction

Rising damp is one of the main problems affecting historic masonry buildings, as it leads to severe consequences, in terms of both bad indoor conditions (high air relative humidity) and materials deterioration [1]. In particular, the presence of moisture in materials' pores, in combination with other environmental factors, may lead to biological attack, salt crystallization, chemical attack, swelling in clay bearing stones, frost damage, etc., finally causing materials loss and even structural problems [2].

The phenomenon of rising damp is very common in ancient buildings due to the presence of water in the ground in the proximity of the masonry and it has been studied long since [3]. The damp occurrence is due to the absence of waterproofing sheets and/or to the fact that traditional "water proofing systems" (e.g., blocks of very compact stones in the course near the ground) could be not sufficient. In a vertical capillary tube immersed at its bottom in a water basin, the rise of water is caused by the capillary forces arising between water and solid surface, due to the high wettability of solid surfaces (low contact angle water/solid), which is verified in the case of hydrophilic materials. In this simple case, the height of water rise (h) can be calculated by the Jurin's law: $h = 2\tau \sin\theta / r\rho g$, where τ is the surface tension of water, θ is the contact angle water/solid, r is the radius of the capillary tube, ρ is the density of water and g is the gravity acceleration.

Bricks, mortars and stones are porous, hydrophilic and hence highly sorptive, thus the driving force making water rise in masonry is capillarity, as in the example described above. However, differently from the case of a capillary tube, masonry is also subject to water evaporation through the internal and external surfaces and this difference makes the phenomenon of rising damp a dynamic rather than a static one [4] (Fig. 1a). In fact, a continuous water flow from ground is present in walls and the maximum height reached by damp is controlled by the relative 'weight' of the three factors involved: water supply from ground, water evaporation and, obviously, characteristics of the building materials (amount and size of pores, pores connectivity and tortuosity, etc.) (Fig. 1b). Modifications of one or more of these three factors result in a different height of rise. Where water supply is abundant, materials are very porous and evaporation is completely inhibited, rising damp may reach impressive heights, as in the case of St. Mark basilica in Venice [5].

2. Aim of the paper

Over approximately last century, the damp-proofing of buildings has become much more efficient and the general expectations about indoor comfort changed. High levels of moisture in walls are considered unacceptable and many repair systems have been proposed for coping with rising damp. However, despite the widespread use of these systems and their application in numerous buildings all over the world, we are far from a deep understanding of their functioning in real masonry and even of their rate of success or failure [1]. Hence, there is still a strong need of experimental results providing evidences on the functioning, effectiveness and limitations of these repair systems, and also on the reasons for their success or failure on site.

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https://doi.org/10.1016/j.culher.2018.04.001
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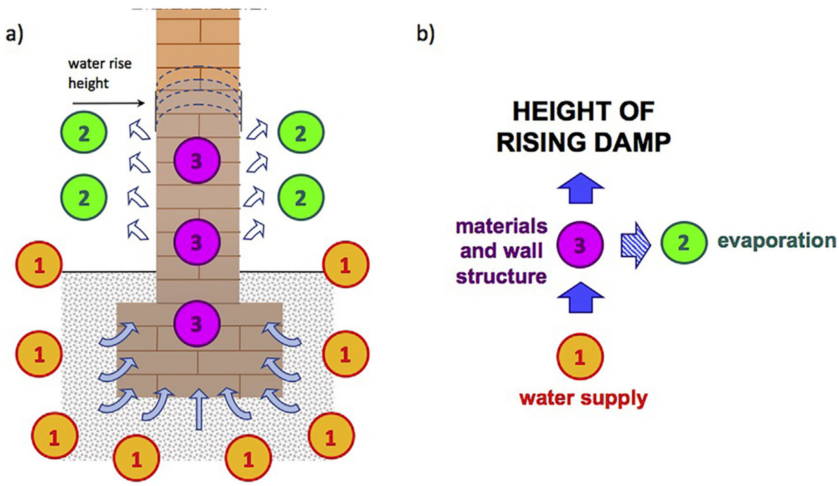

Fig. 1. (a) Dynamics of capillary water rise in a masonry, and (b) schematic representation of the three factors involved, which determine the resulting height of rising damp.

In recent years, coordinated efforts have been made towards this aim, through literature reviews [1,6–8], structured databases [9] and European projects [10].

In this paper, a brief state-of-the-art on the systems for the mitigation of rising damp in masonry is provided, as a contribution towards a better understanding of such systems.

3. Literature survey

In this work, a review of international papers concerning the repair of rising damp in masonry was carried out. These papers include papers published in international journals (both peer-reviewed and not; both available on-line and not), book chapters and contributions in conference proceedings. The scientific literature produced up to 2017 was considered.

A total of 65 papers was found, and their distribution over years is reported in Fig. 2. It can be clearly observed that the literature on this subject is concentrated mostly after 2005 and that year 2017 suggests a pronounced growth of interest.

Within these 65 papers, a distinction was made among: the literature review papers, the papers recommending one or more repair systems (with no experimental results) and the papers presenting experimental results found in laboratory studies and/or on-site surveys. In Fig. 3, the results are shown and some remarks can be done. Firstly, the number of scientific papers (46) is relatively small in proportion to the impact of rising damp in historic buildings and

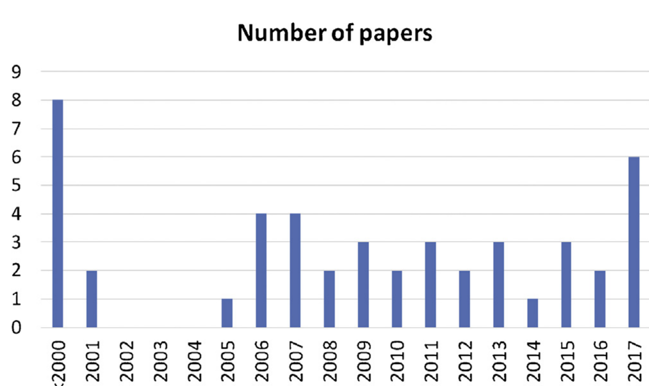

Fig. 2. International papers per year.

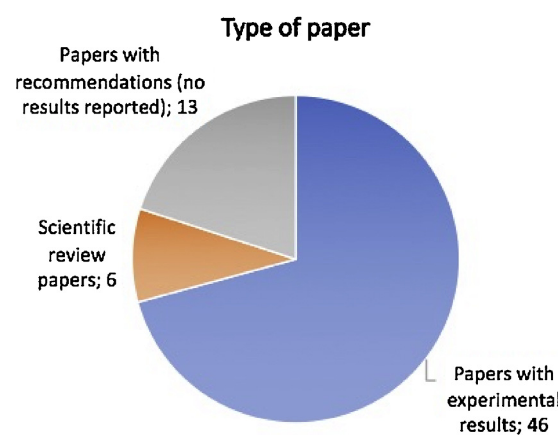

Fig. 3. Number and type of papers found in international literature up to 2017 (included).

the number of repair systems that have been proposed during the last decades, and this suggests that more scientific investigations are needed. Secondly, the number of papers in which repair systems are recommended without providing any experimental evidence or results about their effectiveness (13) is very high in comparison to scientific papers and this surely feeds some confusion in this field. In fact, in these papers the authors state that the relevant systems are effective, also providing examples of buildings in which they were applied, but the statements are not supported by any quantitative data or result. By the way, the present literature survey was not specifically addressed to 'recommendation' papers, hence they were found unintentionally among the others, which means that their actual number is probably higher, especially in the national literature, not considered here. Finally, the number of literature review [6] is quite high in comparison to scientific papers and this might be a sign of the need of making some clearness in a quite confused field.

In this work, only the papers presenting quantitative results on the effectiveness of the repair systems were considered. These were published mostly in international journals, but to a large extent also in conference proceedings (about one third), as shown in Fig. 4 (left).

Within the 46 scientific papers presenting experimental findings, different research approaches were followed, as shown in

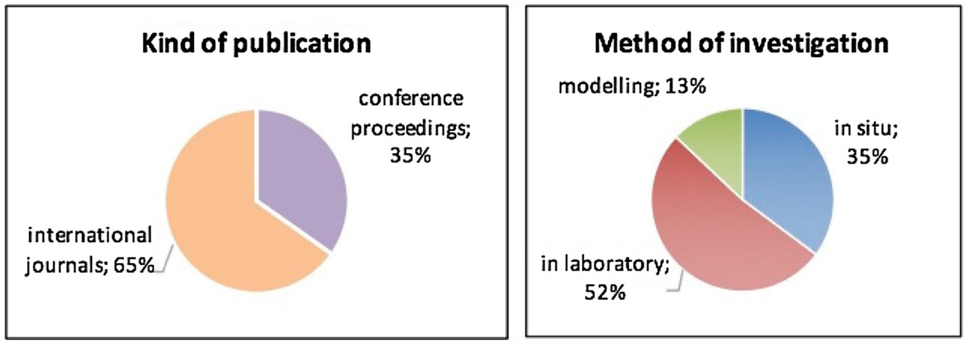

Fig. 4. Left: kind of publication; right: research approach in the international papers examined.

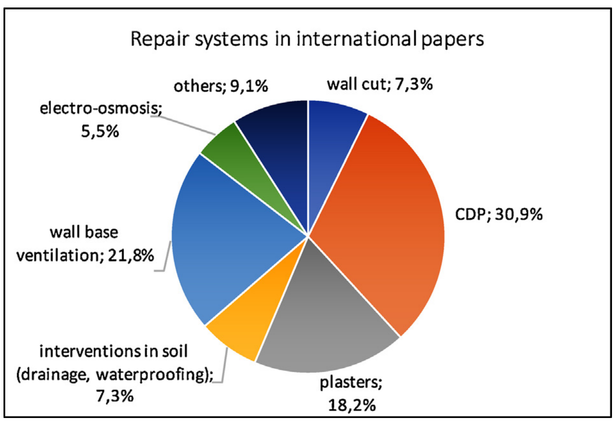

Fig. 5. Repair systems considered in the 46 scientific papers examined (papers investigating more than one system were counted more than one time) (CDP: Chemical Damp Proofing).

Fig. 4 (right) (papers following two approaches were counted twice). The results based on laboratory research are approximately one half. In these researches single materials, composite systems (bricks and joint mortars; bricks and plasters), or real-scale masonry models were used. A 35% of the results is based on in situ surveys, while, notably, a 13% (all constituted by papers published between 2010 and 2017) is based on modelling, which suggests an increasing interest towards this tool. However, not all the relevant papers provide a validation of the modelling results and this means that these researches should be considered still in progress.

4. Current methods for coping with rising damp in masonry

4.1. Systems investigated in the scientific literature

The repair systems in the literature are described below, highlighting the main advantages and drawbacks emerging form the papers. The systems are grouped according to the factor that they address in Fig. 1b, also taking in to account that some systems address two factors contemporarily. In addition, systems based on electro-osmosis are described.

The percentages of papers dealing with the different systems are reported in Fig. 5.

4.2. Systems aimed at reducing water supply from ground

Water supply from ground can be reduced either creating drains or placing waterproof membranes (bitumen- or polymers-based sheets, or clay barriers [11]) along the perimeter of the building, under the ground level, in order to reduce its absorption surface [12,13]. Drains are usually protected with a geotextile to prevent clay depletion from the surrounding soil and filled with coarse aggregate, with water drains at the bottom.

This method is widely recommended for rising damp mitigation [14,15] (since the Romans, actually [1]), but a systematic investigation of its the drying effectiveness is lacking in the literature, as confirmed also by the small number of related papers (Fig. 5). When the drying effect was monitored quantitatively on-site, soil drains and waterproof membranes were not the only systems applied, as a general remediation work had been performed [16].

A further class of systems involves a mixed approach: not only is water supply from ground reduced, but evaporation is increased too. For example, the drains created along the perimeter of the building can be left empty, with upper grids to allow water evaporation. These channels can be also provided with purposely designed natural or mechanical ventilation, creating ventilated air-ducts. In this case, the water supply reduction is secondary, as the main scope is the increase in evaporation, hence these systems are described in the following paragraph.

4.3. Systems aimed at boosting water evaporation

Ventilated air-ducts have been recently proposed to cope with rising damp, especially in heritage buildings, where intervention in masonry walls must be limited, and they have been investigated in several papers (Fig. 5). The air-channels can be made of concrete [17] or masonry [18,19] and can be provided with either a specific or a hygro-regulated mechanical ventilation [20]. The selection of the most suitable size and air ventilation speed can be carried out by modelling [18,21,22], based on the characteristics of the masonry to reclaim; moreover, the use of inside air and outside air can be provided in cold and hot seasons, respectively [23,24]. A significant moisture decrease has been reported in walls of low thickness (up to 40% [18] or more [21]), and a certain drying was found also on-site [24]. However, the testing of this system in the field is still in progress, hence a limited amount of experimental data is available.

A different approach proposed to increase evaporation consists in drilling holes in the masonry and inserting porous tubes (e.g., made of fired-clay, or perforated plastic/metal) inside them [7]. These so-called "Knapen tubes" are usually inclined towards the external surface of the wall (the external end being lower than the end inside the wall) and are expected to boost the evaporation of water, by conveying the moist air out and the dry air in. Although a systematic testing of these tubes is not available, the results found in the literature suggest that they are scarcely effective [25], because the air circulation inside the tubes is not necessarily the expected one, for example in presence of high air relative humidity. Some authors suggest that their (very limited) effectiveness is actually due to the reduction of the cross-section of the wall and that the tubes are useless, as bare holes seem more effective [26]. Finally, tubes disruption was reported for buildings affected by high concentrations of soluble salts [25].

A further approach is based on the application of repair plasters, that are dry ready-to-use mortars which are expected to promote evaporation with respect to traditional ones, but mainly to reduce the damage related salt crystallisation [27]. According to the German WTA specification 2-2-91, repair plasters are characterised by high porosity and water vapour diffusivity ($\mu < 12$), small but still present capillary suction, high salt storing capacity and high resistance to salts and frost damage [28].

Repair plasters are generally manufactured using hydraulic lime, cement or a mixture of them as binder, and adding also air-entraining agents and possibly water-repellents, depending on the type of render. In fact, repair plasters have different operating principles and may be salt-accumulating or salt-transporting [29]. The first ones are aimed at storing the salts inside their macro-cavities for some years, thus avoiding the typical surface damage due to salt crystallisation cycles, and they basically behave as sacrificial renders [27,30]. The second ones, highly wettable and hence usually formulated without water-repellents [31], promote the formation of efflorescence on the surface (supposedly not damaging the underneath material and easy to remove) rather than harmful sub-efflorescence. Salt-blocking and moisture sealing renders, which are aimed at stopping the salts and the water, respectively, at the interface between masonry and render, have been proposed as well, but they are considered counterproductive as they exacerbate the rising damp-related problems [31].

The behaviour and effectiveness of repair renders in laboratory and on-site were investigated in many literature papers, highlighting that:

- the on-site performance of repair plasters is sometimes not satisfactory [27,30,32], due to their premature deterioration. In other cases, a good conservation of these renders was reported after years from their application [28,33];
- the salt transport mechanism may vary from case to case even for the same render, as it depends on several parameters, such as the difference of porosity between plaster and substrate [29], the air relative humidity and ventilation of the surrounding environment [34], the thickness of the plaster [33], etc.;
- the selection of the render to apply should be based on a preliminary assessment of the moisture and salt amounts in the masonry, as well as the characteristics of the existing materials [35,36]. Based on this, the render formulation should be designed, in order to achieve the expected target [29,31,32];
- the commercial renders seldom report their operating principle and only few physical parameters are given [31];
- the literature papers on repair plasters applied to real buildings and real-scale masonry walls are basically addressed to monitoring the salt distribution in the renders and the deterioration patterns of the renders [28,31,34], rather than the moisture amount in the walls [33], which confirms that the main goal of this type of renders is the mitigation of the salt-related damage;
- the final paint used may play a key role and it must be selected not to alter the transport mechanism of the render [37].

Recently, “ventilated” renders with vertical grooves embedded have been proposed, to mitigate the damage by salts crystallisation and also boost evaporation, and the first results seem promising [38].

4.4. *Systems aimed at modifying the materials in the wall*

Two main systems have been proposed for coping with rising damp by modification of the masonry materials and structure.

The first system is the wall cutting [39], i.e. the creation of a physical barrier against capillary rise by mechanical cut (usually sawing) of the wall base and insertion of metallic or polymeric impermeable sheets (such as steel, lead, polyethylene or PVC sheets) [40]. Although corrugated sheets can be used for this purpose, to promote the adhesion with the surrounding materials, the shear resistance of the masonry and hence its seismic behaviour may be affected by the intervention, mostly due to the difficulty of completely filling the cut with repair mortars. However, this aspect was not systematically investigated for existing buildings and only studies on the shear behaviour of sheets applied during the masonry construction are available: these papers conclude that the shear strength of the masonry decreases when sheets are present [41,42].

The principle of this technique is clear and straightforward, but attention must be paid to details, such as the overlapping of the sheets and the sealing in correspondence of pipes, which may jeopardise the success of the intervention [12]. Moreover, the masonry portion below the cut is obviously close to saturation [36].

The second system is chemical damp-proofing (CDP), which consists in forming a moisture barrier layer by injecting a hydrophobic or pore-blocking chemical substance into holes drilled in the cross-section of the wall, as near as possible to the ground [43,44]. A variety of products is available for this purpose [1,45], ranging from inorganic silicates (pore-blocking) to hydrophobic resins and even melt paraffin [43], while only slight differences exist among the application techniques, which are basically injection at low pressure and gravity feed [46]. The spacing between holes is usually about 10–15 cm.

CDP solutions are expected to have a limited impact on the shear performance of masonry, so they are much more diffused than wall cut.

Chemical injections have been largely investigated in the scientific literature [1]. Studies were carried out in laboratory, on single building materials (brick, mortars) [45,47–50], assemblies of materials (bricks and mortars) [49,51–53], real-scale masonry walls [44,46], and on-site [7,25,36,54,55].

Laboratory studies are hard to compare, because the experimental approaches followed are very different. In fact, there is presently no standard procedure for testing the effectiveness of CDP in laboratory and the methods proposed by guidelines and recommendations available at national level are very different [56]. However, laboratory studies in the literature provide very interesting results about the spreading ability and the drying effectiveness of the injected substances in dry, partially wet and saturated building materials. Notably, the spreading ability is a key factor for the creation of a continuous barrier between the holes and the success of the treatment [49], as a non-continuous damp-proof layer, although somehow reducing the water supply to the upper part of the wall, will not stop the capillary flow totally. The papers highlight that there are several parameters to consider. Firstly, the nature of the solvent and its miscibility with water [53,54] and the viscosity of the injected product are fundamental for the displacement of the water already present in the pores. A complete displacement is hard to achieve in fully saturated materials [45,48], while a certain spread can take place when pores are only partially filled with water. However, for some water-based products, a good spreading was found even at high saturation degree [47]. Secondly, the injection pressure [46] and duration [51] are very important for a satisfactory spreading. Finally, the presence of cracks and voids may jeopardise the success of the treatment, because the fluid are prone to percolate inside them rather than to spread in the materials [44], and this aspect is very difficult to evaluate, especially in real masonry walls, where the paths followed by the fluid are basically unknown.

Interesting results were obtained also by testing real-scale masonry walls [44]. A decrease of moisture between 50 and 70% was found in some walls, but in others no clear trend was found comparing treated and untreated specimens.

The on-site surveys on the effectiveness of chemical barriers are quite few. An experimental investigation performed in several Australian buildings in the Seventies highlighted the difficulty in assessing the performance of CDP, due to its dependence on the nature of the building materials under testing [7]. This survey also indicated the need of a systematic evaluation of CDP on-site. The monitoring of a XVIIth century building in Germany, in which three different products were injected and part of the wall was left untreated for comparison, showed that the drying effect was modest and it was attributed to the reduction of the wall cross-section, due to the holes drilling, rather to the products injection [25]. Chemical barriers with different products were tested also in a historic abbey in Belgium [54], but none of the products gave satisfactory results after a monitoring period of 30 months. This was ascribed to the penetration of the fluids in cracks rather than in the materials, the incomplete polymerisation of the resins and the modest spreading ability of the products [54]. An in-the-field investigation was carried out also in a historic stone masonry in Hungary were CDP had been applied [36]. The results show that the masonry below the injection holes was basically saturated, while the upper part exhibited lower moisture amounts, but the absence of data before the intervention and the use of combined repair solutions (including also repair plaster and subsoil insulation) make the results not very conclusive. A thorough on-site investigation was carried out in an old brick masonry warehouse in Copenhagen [55]. A dielectric probe was used for monitoring a wall before and after resin injection, for a total period of 5 years. The results indicate that the decrease of moisture was very small (about ten percent reduction), but they also allow to make some hypotheses about the reasons for it. The presence of hygroscopic salts and the high air relative humidity are regarded as the main causes of the insufficient drying, highlighting the importance of these parameters in the performance of CDP.

The importance of a careful on-site investigation arises from the papers mentioned above. In particular, it seems important to investigate and monitor all the parameters possibly involved in the drying of the masonry, in order to achieve a deep understanding of the reasons for the success or failure of CDP in real masonries. It would be important also to understand if the formation of a partial barrier by chemical damp-proofing provide anyway a decrease in the rising damp level, as suggested by some authors [7,44].

4.5. Electro-osmosis

Scientific papers addressed to investigate the effect of electro-osmosis on masonry walls are very few (Fig. 5).

Active electro-osmosis is expected to cause the migration of water in the pores from the electrodes applied in the moist wall (anode) to the electrodes applied in the soil (cathode), through the application of an external dc electric field. Electro-osmosis exploits the electrokinetic effects connected to water migration in porous materials and has been widely applied to control the moisture amount in clay soils [57]. However, the application of this technique to building materials is not so obvious, mostly because they are stiff and do not shrink when moisture decreases, differently from soils, thus interrupting the electrical continuity of the system [58].

Some papers reported on the occurrence of water flow in different building materials by electro-osmosis [58–60], but also highlighted the importance of the chemical nature [59], the pore size distribution and the pH of the material [61]. The acidification at the anode due to the formation of H+ is a further aspect to consider for the application of permanent electro-osmosis to real buildings [62].

Few on-site surveys of these systems are available in the literature. After testing a brick wall of a building built in the fifties, evidences of water movement due to voltage application (current 0.16–0.47 mA/cm electrode for 9 days) were found, although the drying was considered not sufficient [59]. In this case, the anodic steel electrodes were applied at different heights in the wall, to make some electrodes always available during the water front lowering. A prominent moisture decrease was obtained in a Russian masonry building, upon application of a very high voltage: 200 V for 4 months and then 150–160 V for 3 months [63]. Of course the building was not in use, because so high voltages could not be used in presence of people.

5. Conclusions

The presently available international scientific literature indicates that the drying effectiveness of the systems for fighting rising damp still needs to be fully elucidated. Although these systems have theoretically clear operating principles and have been already applied for decades in masonry buildings, how they actually work in real masonry is still to be fully understood. Through laboratory testing, it was found that several parameters influence the functioning of the techniques against rising damp: the nature and microstructure of building materials, the amount of moisture in the pores, the air relative humidity in the surrounding environment, the presence of hygroscopic salts, etc. However, the complexity of historic masonry buildings makes very difficult to assess the effectiveness of the repair systems in the field. The difficulty of performing an accurate and reliable monitoring of real masonry walls is a further issue to consider in on-site surveys [64].

However, the use of real-scale masonry walls for laboratory testing [31,65,66] and the recent introduction of new and promising embedded sensors to monitor moisture on-site [55,67,68] may contribute to a better understanding of these systems and, in the long-term, to their improvement.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] E. Franzoni, Rising damp removal from historical masonries: a still open challenge, Constr. Build. Mater. 54 (2014) 123–136.
[2] F. Sandrolini, E. Franzoni, An operative protocol for reliable measurements of moisture in porous materials of ancient buildings, Build. Environ. 41 (2006) 1372–1380.
[3] B.H. Vos, Suction of groundwater, Stud. Conserv. 16 (4) (1971) 129–144.
[4] S.J. I'Anson, W.D. Hoff, Water movement in porous building materials–VIII, effects of evaporative drying on height of capillary rise equilibrium in walls, Build. Environ. 21 (1986) 195–200.
[5] F. Sandrolini, E. Franzoni, E. Vio, S. Lonardoni, Challenging transient flooding effects on dampness in brick masonry in Venice by a new technique: the narthex in St. Marco Basilica, in: C.A. Fletcher, T. Spencer (Eds.), Flooding and Environmental Challenges for Venice and its Lagoon: State of Knowledge, Cambridge University Press, Cambridge, 2005, pp. 181–188.
[6] Zhang Z. A review of rising damp in masonry buildings. Advanced Polymer and Composite Research Group. Department of Mechanical and Design Engineering, University of Portsmouth, Anglesea Building, Portsmouth, Hampshire (http://www.wykamol.com/images/pictures/damproofing/lectros/a-review-of-rising-damp-in-masonry-buildings.pdf) (web site access date April 2, 2018).

[7] J.L. Heiman, E.H. Waters, R.C. McTaggart, The treatment of rising damp, Archit. Sci. Rev. 16 (4) (1973) 170–177.
[8] J.M. Delgado, A.S. Guimarães, V.P. de Freitas, I. Antepara, V. Kočí, R. Černý, Salt damage and rising damp treatment in building structures, Advances in Materials Science and Engineering 2016 (2016) [Article ID 1280894].
[9] A.S. Guimarães, J.M. Delgado, Building pathology and rehabilitation techniques-a rising damp treatment catalogue, Def. Diff. Forum 365 (2015) 291–296.
[10] European project Emerisda ('Effectiveness of Methods against Rising Damp in Buildings'), www.emerisda.eu (web site access date April 2, 2018).
[11] M. Michette, R. Lorenz, C. Ziegert, Clay barriers for protecting historic buildings from ground moisture intrusion, Herit. Sci. 5 (2017) 31.
[12] E.B. Møller, B. Olsen, Rising damp, a reoccurring problem in basements: a case study with different attempts to stop the moisture, Nordic Symposium on Building Physics, Tampere, Finland, 29 May–2 June, 2011, pp. 765–772.
[13] P. Lopez-Arce, E. Doehne, J. Greenshields, D. Benavente, D. Young, Treatment of rising damp and salt decay: the historic masonry buildings of Adelaide, South Australia, Mater. Struct. 42 (2009) 827–848.
[14] A.R. Thomas, Treatment of damp in old buildings. Technical Pamphlet 8, Society for the protection of ancient buildings, London, 1992.
[15] P. Trotman, BRE Digest 245 (Building Research Establishment). Rising damp in walls: diagnosis and treatment, IHS BRE Press, Watford, 2007.
[16] J. Fort, Z. Pavlik, L. Balik, R. Cerny, Evaluation of applied remediation works on historical masonry wall exposed to long-term deterioration, in: E. Pellicer, al. et (Eds.), Resilient structures and sustainable construction, ISEC Press, 2017.
[17] M.I.M. Torres, V.P. de Freitas, Treatment of rising damp in historical buildings: wall base ventilation, Build Environ 42 (2007) 424–435.
[18] J. Pazderka, E. Hájková, M. Jiránek, Underground air duct to control rising moisture in historic buildings: improved design and its drying efficiency, Acta Polytech. 57 (5) (2017) 331–339.
[19] L. Tazky, A. Sedlakova, Air channel function for solving moisture problems in buildings, Proc. Eng. 190 (2017) 27–34.
[20] V.P. de Freitas, A.S. Guimarães, Characterization of a hygro-regulated Wall Base Ventilation System for treatment of rising damp in historical buildings, in: C. Rode (Ed.), Proceedings of the 2nd Nordic symposium on building physics, Copenhagen 16-18 June, Denmark, 2008, pp. 911–919.
[21] I.M. Torres, Wall base ventilation system to treat rising damp: the influence of the size of the channels, J. Cult. Herit. (2013), http://dx.doi.org/10.1016/j.culher.2013.03.005.
[22] L. Tazky, A. Sedlakova, Design of the ventilated air channel to resolve moisture problems in the historical church, Energy Procedia 78 (2015) 1323–1328.
[23] A.S. Guimarães, J.M.P.Q. Delgado, V.P. de Freitas, Treatment of rising damp in historic buildings: experimental campaign of wall base ventilation and interface effect analysis, J. Cult. Herit. 20 (2016) 733–738.
[24] V.P. de Freitas, A.S. Guimarães, J.M.P.Q. Delgado, Wall-base ventilation system to control rising damp: a case study of Vilar de Frades historical church in Portugal, Int. J. Architect. Herit. 9 (7) (2015) 859–865.
[25] J. Vogeley, Protection against rising damp in masonry: the baroque palace in Ludwigsburg, a case study. In: Building appraisal, maintenance and preservation. Proceedings of a 3-day symposium at the university of Bath, 10th-12th July 1985, Department of architecture and building engineering, Bath, 1985, pp. 113–123.
[26] J.L. Heiman, An evaluation of methods of treating rising damp, in: M. Lieff, H.R. Trechsel (Eds.), Moisture migration in buildings, ASTM STP 779. American Society for testing and materials, 1982, pp. 121–137.
[27] B. Lubelli, R.P.J. van Hees, C.W.P. Groot, Sodium chloride crystallization in a "salt transporting" restoration plaster, Cement Concrete Res. 36 (2006) 1467–1474.
[28] K. Droll, H.G. Meier, Cross-sectional water-repellent treatment of repair mortars. Experiences from long-term behaviour, In: Proc. Hydrophobe I, TU Delft, The Netherlands, 1995.
[29] C. Groot, R. van Hees, B. Lubelli, T. Wijffels, M. de Rooij, J. Petkovic, Aspects of salt and moisture transport in restoration plasters and renders, Restor. Build. Monum. 10 (6) (2004) 593–608.
[30] M. Pavlíková, Z. Pavlík, M. Keppert, R. Černý, Salt transport and storage parameters of renovation plasters and their possible effects on restored buildings' walls, Constr. Build. Mater. 25 (2011) 1205–1212.
[31] L. Falchi, E. Zendri, E. Capovilla, P. Romagnoni, M. De Bei, The behaviour of water-repellent mortars with regards to salt crystallization: from mortar specimens to masonry/render systems, Mater. Struct. 50 (2017) 66, http://dx.doi.org/10.1617/s11527-016-0891-8.
[32] R.P.J. van Hees, S. Naldini, J. Delgado Rodrigues, Plasters and renders for salt laden substrates, Constr. Build. Mater. 23 (2009) 1714–1718.
[33] V. Fassina, M. Favaro, A. Naccari, M. Pigo, Evaluation of compatibility and durability of a hydraulic lime-based plaster applied on brick wall masonry of historical buildings affected by rising damp phenomena, J. Cult. Herit. 3 (2002) 45–51.
[34] B. Lubelli, R.P.J. van Hees, C.W.P. Groot, Investigation on the behaviour of a restoration plaster applied on heavy salt loaded masonry, Constr. Build. Mater. 20 (2006) 691–699.
[35] R. van Hees, S. Naldini, B. Lubelli, The development of MDDS-COMPASS, Compatibility of plasters with salt loaded substrates. Constr. Build. Mater. 23 (2009) 1719–1730.
[36] A. Dudás, A. Terjék, Efficiency assessment of posterior waterproofing systems of renovated porous limestone masonry work, Tehnički Vjesnik 22 (5) (2015) 1225–1236.
[37] M. Karoglou, A. Bakolas, A. Moropoulou, A. Papapostolou, Effect of coatings on moisture and salt transfer phenomena of plasters, Constr. Build. Mater. 48 (2013) 35–44.
[38] A. Fragata, M. Rosário Veiga, A. Velosa, Substitution ventilated render systems for historic masonry: Salt crystallization tests evaluation, Constr. Build. Mater. 102 (2016) 592–600.
[39] F.L. Tamas, I. Tuns, Modern solutions to eliminate capillarity moisture from brick walls–Comer method, Institutul Politehnic din Iasi, Buletinul. Sectia Constructii. Arhitectura 54 (4) (2008) 15–18.
[40] D.J. Gavrilović, Building waterproofing remediation applying the "total cut" method. Facta Universitatis, Series Architect. Civil Eng. 9 (1) (2011) 105–118.
[41] N. Mojsilović, G. Simundic, A. Page, Masonry wallettes with damp-proof course membrane subjected to cyclic shear: an experimental study, Constr. Build. Mater. 24 (2010) 2135–2144.
[42] N. Mojsilović, Masonry elements with damp-proof course membrane: assessment of shear strength parameters, Constr. Build. Mater. 35 (2012) 1002–1012.
[43] J. Dreyer, C. Hecht, Injection methods for retrofitting of moisture damaged constructions. In: Structural Studies, Repairs and Maintenance of Historical Buildings, Tran. Built. Environ. 55 (2001) 517–526.
[44] G. Alfano, C. Chiancarella, E. Cirillo, I. Fato, F. Martellotta, Long-term performance of chemical damp-proof courses: twelve years of laboratory testing, Build. Environ. 41 (2006) 1060–1069.
[45] R.W. Sharpe, Injection systems for damp-proofing, Build. Environ. 12 (1977) 191–197.
[46] V. Eusebi, R. Montagna, M. Pauri, A. Stazi, Recovery of rising-damp damaged masonry: experimental comparison between 'slow diffusion' and 'under pressure' procedures for waterproofing agents, in: N.G. Shrive, A. Huize (Eds.), Proc. 10th IB2MAC, Calgary, Canada, July 5-7, 1994, pp. 819–828.
[47] G.J. Pleyers, Treatment of rising damp in wet conditions with new hydrophobic pore filling resins, in: In: Proc. Hydrophobe III, 3rd International Conference on Surface technology with water repellent agents, Universität Hannover, Germany, September 25th and 26th, 2001, Aedificatio Verlag, Freiburg, 2001, pp. 247–256.
[48] L. Mao, D. Kagi, Method for assessing liquids for the remedial treatment of rising damp, in: In: Proceedings of the International Colloquium on Methods of evaluating products for the conservation of porous building materials in monuments, Rome 19-21 June 1995, ICCROM, Rome, 1995, pp. 359–371.
[49] A. Hacquebord, B. Lubelli, R. van Hees, T. Nijland, Evaluation of spreading and effectiveness of injection products against rising damp in mortar/brick combinations, Proc. Chem. 8 (2013) 139–149.
[50] Y. Vanhellemont, H. De Clercq, A. Pien, A proposal for test procedure for injection products against rising damp, in: H. De Clercq, A.E. Charola (Eds.), Hydrophobe V, 5th International Conference on Water repellent Treatment of Building Materials, April 15-16, 2008, Aedificatio Verlag, Freiburg, 2008, pp. 165–170.
[51] S.J. I'Anson, W.D. Hoff, Chemical injection remedial treatments for rising damp–II. Calculation of injection times, Build. Environ. 25 (1) (1990) 63–70.
[52] R.P.J. van Hees, J.A.G. Koek, Treatment of rising damp. A laboratory evaluation method, in: In: Proceedings of the International Colloquium on Methods of evaluating products for the conservation of porous building materials in monuments, Rome 19–21 June 1995, ICCROM, Rome, 1995, pp. 403–418.
[53] S.J. I'Anson, W.D. Hoff, Chemical injection remedial treatments for rising damp–I. The interaction of damp-proofing fluids with porous building materials, Build. Environ. 23 (3) (1988) 171–178.
[54] R.P.J. van Hees, J.A.G. Koek, Treatment of rising damp. Evaluation of six chemical products, in: J. Riederer (Ed.), Proceedings 8th International congress on deterioration and conservation of stone, Berlin, 1996, pp. 1435–1446.
[55] P.L. Larsen, Determination of water content in brick masonry walls using a dielectric probe, J. Architect. Conserv. 18 (1) (2012) 47–62.
[56] E. Franzoni, E. Rirsch, Y. Paselli, Laboratory models for the assessment of the effectiveness of chemical damp-proofing in masonry: existing methods and some proposals for new fixtures, in: K.K. Hansen, C. Rode, L.-O. Nilsson (Eds.), Proceedings of the International RILEM Conference Materials, Systems and Structures in Civil Engineering 2016, 22-24 August, Lyngby, Denmark - Segment on Moisture in Materials and Structures, RILEM Publications S.A.R.L., Paris, France, 2016, pp. 299–308.
[57] L. Casagrande, Electro-osmotic stabilization of soils, J. Boston Soc. Civil Eng. 39 (1) (1952) 51–83.
[58] L. Bertolini, L. Coppola, M. Gastaldi, E. Redaelli, Electroosmotic transport in porous construction materials and dehumidification of masonry, Constr. Build. Mater. 23 (2009) 254–263.
[59] L.M. Ottosen, I. Rörig-Dalgård, Drying brick masonry by electro-osmosis, In: Proceedings of the 7th International masonry conference, London 30th Oct.–1st Nov, 2006 (cd-rom, paper #31).
[60] J.M. Paz-García, B. Johannesson, L.M. Ottosen, A.N. Alshawabkeh, A.B. Ribeiro, J.M. Rodríguez-Maroto, Modeling of electrokinetic desalination of bricks, Electrochim. Acta 86 (2012) 213–222.
[61] C. Andrade, M. Castellote, J. Sarria, C. Alonso, Evolution of pore solution chemistry, electro-osmosis and rebar corrosion rate induced by realkalization, Mater. Struct. 32 (1999) 427–436.
[62] L.M. Ottosen, I.V. Christensen, Electrokinetic desalination of sandstones for NaCl removal—Test of different clay poultices at the electrodes, Electrochim. Acta 86 (2012) 192–202.

[63] E.A. Ivliev, Electroosmotic drying of building walls and basements, Surf. Eng. Appl. Electrochem. 43 (4) (2007) 291–296.
[64] State-of-the-Art Report of RILEM TC 248-MMB ("moisture measurement in building materials and structures"), accepted, in press.
[65] E. Franzoni, F. Sandrolini, S. Bandini, An experimental fixture for continuous monitoring of electrical effects in moist masonry walls, Constr. Build. Mater. 25 (2011) 2023–2029.
[66] L. Pereira-de-Oliveira, P. Guterres, J. Lanzinha, An experimental model for rehabilitation rendering mortar submitted to rising damp, In: Proc. of REHABEND 2016, May 24-27, 2016, Burgos, Spain (CODIGO: 2.2.28).
[67] R. Agliata, L. Mollo, R. Greco, Use of TDR to compare rising damp in three tuff walls made with different mortars, J. Mater. Civil Eng. 29 (4) (2016) 04016262.
[68] A. Cataldo, E. De Benedetto, G. Cannazza, G. Monti, E. Piuzzi, TDR-based monitoring of rising damp through the embedding of wire-like sensing elements in building structures, Measurement 98 (2017) 355–360.